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GPS For GIS : Getting the Appropriate Combination

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Abstract

The concept of using GPS as a 'real-world' digitiser for GIS applications has attracted the attention of many GIS users. The apparent ease-of-use of GPS, however, has meant that many users are unaware of the limitations of the system. Depending on the type of system (hardware and software) and data collection procedure employed, GPS technique can give positioning accuracies ranging from few millimetres to a hundred metres or so. On the other hand, different GIS applications require different levels of data accuracy, mainly a function of the "scale" of the database. The question then is: which GPS system should one use for their GIS need? This paper describes a variety of GPS systems which give different accuracies. An emphasis is given to systems based on low-cost GPS instrumentation ("sensors" and "engines" - C/A-code single frequency receivers) which may be more economically appropriate to use for most GIS applications. More importantly, issues regarding system accuracy, which GPS users need to be aware of, are addressed. Among the important ones are; (1) What level of reliability is the accuracy associated with? (2) What observation conditions or constraints need to exist for this accuracy to be guaranteed? In this paper, C/A-code-based systems are tested and their performance characteristics are discussed. In addition, limitations of the systems with regards to observation conditions are discussed.

1.0 INTRODUCTION

The concept of using GPS as a coordinate data capture for GIS applications, which started as early as 1987 (Colwell, 1991), has since attracting the attention of many GIS users. The apparent ease-of-use of GPS, however, has kept many users unaware of the limitations of the system (Masters et al., 1993).

Positioning with GPS technology can delivers wide spectrum of accuracy. Depending on the type of system (hardware and software) as well as data collection procedures employed, GPS technique can give positioning accuracies ranging from few millimetres to a hundred metres or so (Rizos et al., 1995).

On the other hand, different GIS applications require different levels of data accuracy, mainly a function of the "scale" of the database (Masters et al., 1993). Understandably, small scale databases would require low level data (positioning) accuracy while large scale databases requires higher level of accuracy. Three accuracy level are normally use for GIS databases (Corcoran, 1995) as indicated in Table 1 below.

Level	Accuracy
low	50 - 100 m
medium	2 - 10 m
high	0.1 - 2 m

Table 1: Accuracy level associated with GIS databases.

The question to ask then is: which GPS system should one use for their GIS need, i.e., which GPS system could give the required positioning accuracy? When considering data capture and compilation are estimated to be between 60 percent to 80 percent of the total GIS implementation cost (ibid, 1995), weighting the appropriate GPS system to match the GIS accuracy requirement is vital.

Equally important is also to ask the extent of "validity" for such an accuracy statement. For example; system A claimed to give sub-metre accuracy. Further question then would be, which level is this performance can be relied upon? Would that accuracy attainable under the operational constraints that would be faced?.

Apart from this, the same GPS system, might give different position accuracy when used on different sets of observation conditions, in other words, the accuracy is also being effected by some observation conditions or constraints. Hence, statement of the performance characteristic of a GPS system should not only state an accuracy statement alone, but also related association to the accuracy for example, the most important being the level of reliability and the observational constraints. Understanding this issue are thus necessary.

This paper first highlighted on the availability of GPS systems which on the consequence gives different level of positioning accuracy. GPS systems based on low-cost instrumentation, which are more suitable to use for GIS applications are then presented. Issues in defining the performance characteristics of a GPS system are then discussed. Results from benchmarking the performance characteristics of several low-cost GPS systems suitable to be use in GIS applications are finally presented which are finally recommended for GIS use.

2.0 ISSUES REGARDING GPS POSITIONING ACCURACIES

GPS positioning *accuracy* are known to be influenced by several factors. Among these the significant one being; the observation type, the signal disturbances present, the algorithm used and the operational conditions (Rizos et al., 1995).

The *observation type* would determine the precision of the observation measurement. The observation may be the C/A and/or the Precise pseudo-range, the carrier phase, and the Doppler. The standard C/A-code measurement precision is at the few metres level, while the P-code measurement accuracy is at several decimetre level. Although the P-code are not generally available in the low-cost GPS instrumentation, some new receivers, utilising the 'narrow-correlator' technology, can make C/A-code measurements to about the same level of precision as the P-code measurements (Lachapelle et al., 1992) hence sometimes being referred as Precise C/A-code (Subari, 1996). The carrier-phase, although being an ambiguous range, can be measured to ten to hundred fold higher precision than using the codes. The Doppler which are normally derived from the carrier-phases, thus having similar precision as the carrier-phase, are not often use for position computation purposes, for e.g., computing velocity of a trajectory in most navigation receivers, or used to smoothed the codes.

The *signal disturbances* introduce systematic biases in the observations, but most of them are beyond the control of the users. The salient one are the ionospheric delay, the tropospheric delay and the multipath.

The *algorithm* used to process the observation will determine the level of the treatment of the existed biases in the data. Most algorithm utilises observation differencing method to eliminates these biases based on the common characteristics between satellites and stations. The computed position accuracy will thus reflect the magnitude of the residuals (the left-over) of these biases.

Assuming a certain measurement precision, and the presence of an 'acceptable' level of residual biases, it is the *operational issues* that will influence the positioning accuracy the most. These operational constraints or conditions can further be classified as user influenced or non-user influenced (Subari, 1996). The non-user controlled issues include the satellite geometry, while the user-controlled issues are the length of the observation session, the mode of operation (such as whether the positioning mode is static or kinematic) and the separation of the antennas (i.e., the baseline length).

Hence, a proper *performance characteristic* statement for a GPS system should not merely gives a blanket accuracy statement, but also to include; 1) the level of *reliability* which this accuracy corresponds to, and 2) the operational constraints that must be specified to ensure this accuracy and reliability (Rizos et al., 1995).

Reliability is defined in this context as a measure of the ***degree of repeatability*** of the accuracy of the results given by the system, measured in the form of a percentage. If the obtainable positioning accuracy is stable, it suggested that the reliability of the system is high, while if the obtainable positioning is highly variable, then the reliability of the system is considered to be low. Common figure taken for reliability statement is 95% or 99% (e.g., for 95% reliability level, the acclaimed accuracy is true in 19 out of 20 trials). Note that GPS performance is also stated at the 95% level.

3.0 VARIETY OF GPS SYSTEMS

For some 'established' applications of GPS for positioning, e.g., surveying and navigation, and recently Differential GPS (DGPS), to some extent, GPS systems employed for these applications has been 'standardised', in the sense that systems requirements for specific applications has been well-identified.

High precision surveying (below and up to few tenth of *ppm* or part-per-millionth - surveying accuracy is measured in relative terms, generally as a function of receiver separation. For example 10 ppm translates to 10 centimetre uncertainty in a 10 km baseline) is generally addressed using 'top-of-the-line' GPS systems. The hardware is of the dual-frequency type enabling both the L1 and L2 carrier-phase measurement to be made while employing double differencing technique with ambiguity fixing solution, as a standard algorithm, in the data processing part.

Low precision positioning (100 metre accuracy, e.g., in support of most navigation requirements) is addressed by inexpensive 'navigation-type' GPS systems, which requires only the standard C/A-code measurement for the point positioning algorithm used.

Differential GPS (DGPS) on the other hand, uses GPS systems enabling C/A-code differential correction computed in the base station to be transmitted and applied to the rover receiver. This type of systems deliver accuracies in the range of 2-5 meters.

Between the systems intended for DGPS and high precision surveying applications, that is, those intended to address accuracies in the sub-meter to meter level, (which is where most of the GIS applications are) however, no clear guidelines on systems (instrumentation and procedures) are available (Subari and Rizos, 1995). While most of the commercially available systems are mainly driven by vendor-based product, rather than by application-based standards and specifications.

In the past several years, a new class of GPS receivers has been introduced in the market, a category which falls between the standard surveying receivers and the navigation receivers. Some of these receivers are capable of tracking phase or phase-related data with option of outputting the raw-tracked data. Some other, utilising the narrow-correlator technology, can measures C/A-code data to about the same level of precision as the P-code measurements (termed as the Precise C/A-code, or PC/A-code).

These single frequency C/A-code based receivers, which comes with only little operational software, are most of them navigation receivers, with additional phase measuring capability grafted to them (Rizos et al., 1994). Most of these receivers are available in the form of GPS "engines" or "sensors", which are meant to be use for GPS-integrated system developments.

In this investigation, several GPS systems were configured and tested. Emphasize was for systems based on low-cost GPS hardware, in view to maintained the capital cost for GPS instrumentation at the minimum.

4.0 BENCHMARKING LOW-COST GPS SYSTEMS

For the purpose of this investigation, GPS system is defined as a combination of; (1) The type of measurement used (which would then determine the type of instrumentation), and (2) The algorithm employed in the data processing strategy (which is the software part). System configuration to some extent, is still following the 'standard' surveying system such as; relative positioning in static mode (i.e., two receivers are employed at one time, with a 'span' of observation session). In this investigation, seven GPS systems were configured and tested (as in Table 2).

The GPS system configurations are based on the measurement type being use and the data processing algorithm employed. The measurement type being the standard C/A-code, the Precise C/A-code (PC/A-code), and the L1 carrier-phase. These are measurement types most likely available on a single-frequency low-cost GPS receivers. The system could use any single measurement or a combination of them. The algorithm for the data processing is the commmon double and triple-differencing techniques.

System	Measurement type	Data processing algorithm
1	C/A-code	Double-diff.
2	PC/A-code	Double-diff.
3	L1 carrier-phase	Triple-diff.
4	L1 carrier-phase	Double-diff. (amb. free)
5	L1 carrier-phase	Double-diff. (amb. fixed)
6	C/A-code + L1	Double-diff. (amb. free)
7	PC/A-code + L1	Double-diff. (amb. free)

Table 2: Several Low-Cost GPS Systems

An *investigative test* was carried out during August - September 1996, to determine the *performance characteristic* of these low-cost GPS systems, in particular the achievable positioning accuracy and the reliability level of the systems. These performance characteristics were then related to the *observing conditions*. Several baselines of lengths varying from about 2 to 35 kilometres representing the likely 'scale' of GIS applications were observed. 24 hours of data were collected on each baseline to sample all satellite distribution geometries, as well as varying atmospheric contributions.

The data were then processed using an in-house GPS data processing software, which has the capabilities of processing individual or mixed measurement types, in various data reduction algorithms. Varying observation length are used in the data processing. In the course of this investigation, tenth of thousands of baseline solutions has been generated for each systems, enabling the achievable accuracy of such system to be established, and the reliability level to be determined, under known certain observational conditions. Complete result of the investigation is reported in Subari (1996). The following are summary of the result of the test.

5.0 GPS FOR GIS: RECOMMENDATIONS

GPS system for GIS can be very well served by the low-cost GPS system range, based on the C/A-Code single frequency instrumentation. For most of GIS applications, the following low-cost GPS system configurations are recommended, with matching position accuracy performance as opposed to the observation period, as summarised in Table 3. These performance characteristics were stated for 95% of the time (of a 24 hour period), for station separation up to about 30 km, using 5 or more satellites.

Positional Accuracy	Low-Cost GPS System	Observation span
5 m	C/A-code	Single-epoch
2.5 m	PC/A-code	Single-epoch
	C/A-code	5-10 minutes
1.0 m	PC/A-code	5-10 minutes
	Mixed PC/A-code+L1 phase	1-2 minutes
0.5 m	Mixed PC/A-code+L1 phase	5-10 minutes
	DD* or TD^ L1 phase	10-30 minutes
10-30 cm	DD L1 phase (ambiguity float)	60 minutes
<10 cm	DD L1 phase (ambiguity fixed)	> 60 minutes

*DD - Double-differencing data processing
^TD - Triple-differencing dat aprocessing

Table 3: Matching Positioning Accuracy With Low-Cost GPS Systems

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Bibliography

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